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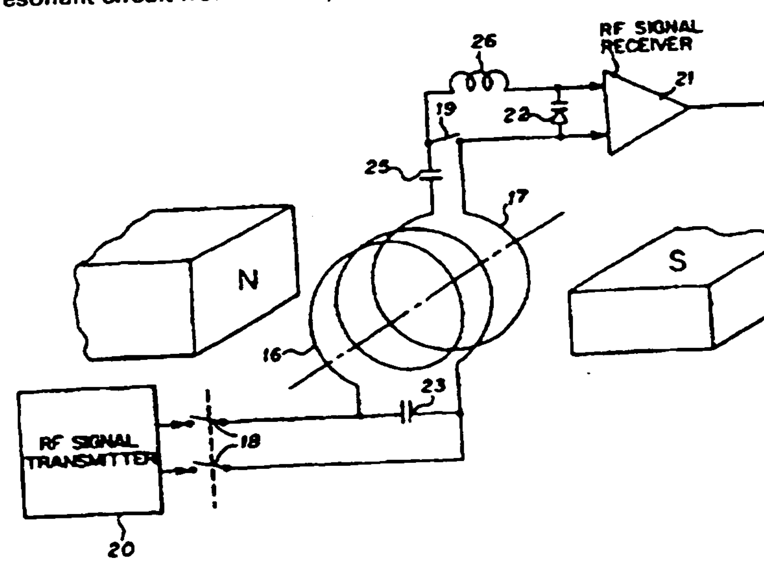
(54) Abstract Title
Antenna system for NMR and MRI apparatus

(57) An antenna system for use in an NMR or MRI apparatus which includes a radio frequency (RF) signal transmitter (20) and a radio frequency (RF) signal receiver (21). The antenna system includes at least first and second electromagnetically coupled resonant circuits the first resonant circuit comprising a first inductance coil (16) producing a first electromagnetic field flux vector, and the second resonant circuit comprising a second inductance coil (17) producing a second electromagnetic field flux vector, the first electromagnetic field flux vector having a component parallel to the second electromagnetic field flux vector. A switch system (18, 19) is coupled to the first and second resonant circuits. The switch system has a first switching position for coupling the first resonant circuit to an output of the RF signal transmitter and preventing a signal from the second resonant circuit from being fed to an input of said RF signal receiver, and a second switching position for permitting an RF signal from the second resonant circuit to be fed to an input of the RF signal receiver and disconnecting the first resonant circuit from the output of the RF signal transmitter.



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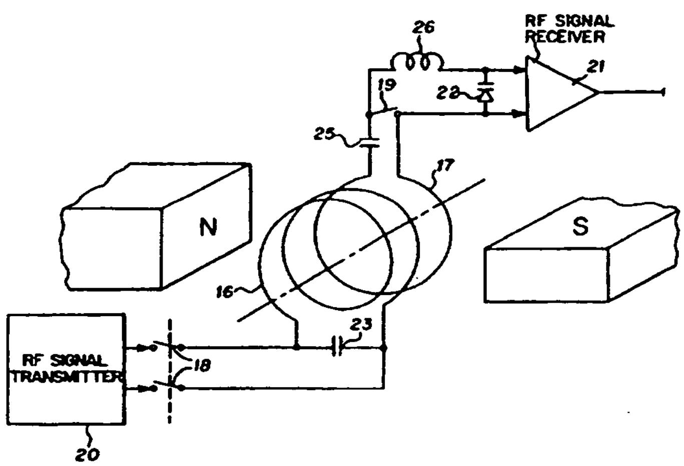

(57) Abstract

An antenna system for use in an NMR or MRI apparatus which includes a radio frequency (RF) signal transmitter (20) and a radio frequency (RF) signal receiver (21). The antenna system includes at least first and second electromagnetically coupled resonant circuits, the first resonant circuit comprising a first inductance coil (16) producing a first electromagnetic field flux vector, and the second resonant circuit comprising a second inductance coil (17) producing a second electromagnetic field flux vector, the first electromagnetic field flux vector having a component parallel to the second electromagnetic field flux vector. A switch system (18, 19) is coupled to the first and second resonant circuits. The switch system has a first switching position for coupling the first resonant circuit to an output of the RF signal transmitter and preventing a signal from the second resonant circuit from being fed to an input of said RF signal receiver, and a second switching position for permitting an RF signal from the second resonant circuit to be fed to an input of the RF signal receiver and disconnecting the first resonant circuit from the output of the RF signal transmitter.

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TITLE

ANTENNA SYSTEM FOR NMR AND MRI APPARATUS

CROSS REFERENCE TO RELATED APPLICATION

This is a Continuation-in-Part of my prior application Serial No. 08/656,766, the entire contents of which are incorporated herein by reference.

BACKGROUND OF THE INVENTION

1. FIELD OF THE INVENTION

The present invention is directed to transmission and reception antennas for use in a nuclear magnetic resonance (NMR) apparatus and in a magnetic resonance imaging (MRI) apparatus, for calculating spectra or generating images of an examination subject or object.

2. DESCRIPTION OF THE PRIOR ART

Nuclear magnetic resonance (NMR) is the effect of a resonant rotating or alternating magnetic field, imposed at right angles to a static field, to perturb the orientation of nuclear magnetic moments.

Magnetic resonance imaging (MRI) is the development of nuclear magnetic resonance (NMR) techniques for obtaining a diagnostic scan of a subject such as a human or animal body.

The patient or examination subject is placed in a strong magnetic field. This magnetic field induces a net magnetization of the nuclei in the subject. A short radio frequency pulse (RF pulse) is applied at the Larmor frequency of the precessing nuclei which, in turn, emit an RF signal of the same frequency. This is detected and gives a "fingerprint" of the environment of the nucleus being studied. This information is one-dimensional but is converted into a two-dimensional anatomical image by adding a gradient to the applied magnetic field which results in a frequency modulation of the emitted RF signal. A series of such measurements is analyzed by computer to generate the image.

In an NMR apparatus, as well as in an MRI apparatus, a strong magnetic field aligns the nuclei of the subject or

object to be studied along the field direction. A radio frequency field delivered through a transmitter antenna, also known as the transmitter coil, brings the nuclei to a higher energy state.

A receiver antenna, also referred to as a receiver coil, intercepts the signal emitted by the object (patient) as its nuclei precess or relax from the higher energy state.

The conditions of efficient energy absorption require that the RF fields of the transmitter and receiver antennas be orthogonal to the static magnetic field. The simultaneous condition of negligibly low interaction between the receiver and transmitter antennas for minimal mutual distortion of their RF fields and for the prevention of high transmitter power to be applied to the receiver, in part also means that the RF fields of the transmitter and receiver antennas must be orthogonal even though transmission and reception do not coincide in time. Acceptable switching time between the two is of the order of about ten microseconds.

As represented by Fig. 1, which shows the prior art, a radio frequency (RF) transmitter 4 transmits a signal to a transmitter antenna 2. The signal which is absorbed and subsequently re-emitted by the examination body or subject (patient) 5 is then picked up by a receiver antenna 1 and fed to a radio frequency (RF) receiver 3. The examination body or subject 5 which is being scanned is within the RF fields of both the transmitter and receiver antennas 2,1. The transmitter antenna 2 and receiver antenna 1 are optimized for their respective tasks and are tuned by variable capacitors 6 and 7. Normally, the single, fixed in place transmitter antenna 2 is big enough to encompass the largest part of a body or subject 5 to be scanned. Significantly smaller reception antennas 1, specialized for different body parts, are separately connected and used. Magnet poles 8 and 9 are shown located above and below the patient (body or subject 5), respectively.

Because of the orthogonal arrangement and spatial separations of the transmitter antenna 2 and receiver

antenna 1, the resulting low electromagnetic coupling between the transmitter antenna 2 and receiver antenna 1 assures low field distortion and allows utilization of speedy and efficient electronic tuning for the receiver antenna 1. The required transmitting power is high and manual tuning of the transmitter antenna 2 by a variable capacitor 6 is employed, for no known electronically controlled semiconductor device may withstand the incident power.

Another limitation of the prior art apparatus is that the magnet gap between magnet poles 8 and 9 should be large enough to receive the two separate antennas 1, 2 therebetween, which is not always possible or cost efficient.

These prior art types of devices are described, for example, in U.S. Patent Nos. 4,926,126; 4,975,644; 5,144,244; and 5,256,972, the entire contents of which are incorporated herein by reference.

Figure 2 represents another prior art apparatus using a single antenna 10 which is alternatively switched by switch 14 between the RF signal transmitter 12 and RF signal receiver 13. The antenna 10 is tuned by a variable capacitor 11.

In the case of Fig. 2, the transmitter power requirement is significantly lower as compared to the embodiment of Fig. 1. The antenna 10 is not limited to a single orientation but may be multi-orientable. The antenna 10 also does not put a large constraint on the size of the magnet gap. These prior art types of devices are described, for example, in U.S. Patent Nos.
4,901,022 and 5,166,617, the entire contents of which are incorporated herein by reference. However, even though the transmitter power is lower in the embodiment of Fig. 2, the transmitter power requirement is still so high as to prevent simple implementation of electronic antenna tuning.

SUMMARY OF THE INVENTION

An object of the present invention is to provide a unique antenna circuitry for use in NMR and MRI apparatus

wherein a single antenna utilizing a plurality of interacting inductance coils is positioned so as to enclose the object or subject to be scanned in its transmitting and receiving RF fields.

A further object is to provide an antenna which can be electronically tuned through a varactor (an electronically controlled variable capacitor), which needs only low transmitter power, which is small and is multi-orientable, and which has high sensitivity at reception.

According to the invention, an antenna system comprises at least two electromagnetically coupled resonant circuits. The inductance coils in each resonant circuit is comprised of a coil producing an RF (radio frequency) field fully or partially enclosing the examination object or subject. The combined RF field, which is a result of interaction between the resonant circuits, excites the nuclei of the full volume of interest and subsequently intercepts the signal emitted by those nuclei as they relax from their higher energy state.

As proximately positioned coils normally have a level of electromagnetic coupling of a few percent only, this low level of interaction leads to a frequency response curve of the combined resonant circuit which approximates a multiplication of separate frequency response curves for each resonant circuit. This, in turn, contributes to higher selectivity and sensitivity of the antenna at reception, as compared to a single resonant circuit.

One of the resonant circuits is connected to a transmitter through a first switch device which, in its closed position, forwards the transmitter power to the antenna during the transmitting RF pulse. Another resonant circuit is connected to the receiver. This second resonant circuit incorporates a tuning varactor and a second switch device. The second switch device shorts, during transmission, the part of the resonant circuit which includes the varactor and the receiver input, thus protecting them from the excessive power during transmission. The combined resonant frequency of the antenna during transmission is

controlled by a variable capacitor in the first resonant circuit.

At the time of reception, all switch devices are open, causing the transmitter to be disconnected from the antenna, while the receiver input is freed to pick up a signal, and the varactor is used to control the combined resonant frequency.

Since the antenna is located in the very proximity to the examination object, transmitting power requirements are minimal. By using an ohmic resistance on the transmitter side of the first switch device, antenna bandwidth at transmission can be artificially widened, making the antenna substantially indifferent to load variations at the expense of somewhat higher transmitter power requirements. Thus, the reception bandwidth is not influenced and retains its prior high selectivity properties.

The first and second switch devices are easily implemented by using a pair of oppositely interconnected diodes for each connectivity link. Application of transmitter power causes the diodes to conduct, effectively shorting them (i.e., effectively closing the switch) and allowing the power to proceed or pass through. Removal of transmitter power brings the diodes back into a high impedance nonconductive state (i.e., switch open).

The antenna can be positioned at a multitude of orientations in a NMR or MRI apparatus as long as its electrical axis remains perpendicular to the static magnetic field. This property makes it particularly suitable for kinematic orthopaedic examinations.

The antenna system of the present invention is fail-safe. Nonpermissible and unintended high levels of RF power are avoided by the inherent features of low required power and by automatic detuning of the antenna in a case of a single or plural components failure.

Those skilled in the art will understand that the principles presented herein allow antenna implementation in a multitude ways which depend on particular application

specific requirements: such as Larmor frequency, examination subject or object, magnet field orientation. It will also be clear that a multitude of components can be used instead of those described, for example: any type of variable capacitor can be used in place of a varactor, a set of capacitors can be used in place of any single capacitor, (the same with respect to the varactor), and an electronically controlled switch can be used in place of a pair of oppositely interconnected diodes. Because the level of transmitted power is low and readily available, the bandwidth of the antenna at transmission may be artificially widened, which means a wide frequency range, and the system seldom requires transmission frequency tuning.

BRIEF DESCRIPTION OF THE DRAWINGS

Fig. 1 is a schematic representation of a conventional nuclear magnetic resonance (NMR) or magnetic resonance imaging (MRI) apparatus of a type comprising separate transmission and reception antenna systems.

Fig. 2 is a schematic representation of a conventional NMR or MRI apparatus having one antenna system.

Fig. 3 is an electrical schematic of the antenna system of the present invention.

Fig. 3A is a partial schematic showing a modification of the embodiment of Fig. 3.

Figs. 3B and 3C are partial schematic views showing diode switches replacing the switches shown schematically in Fig. 3.

Fig. 4 is a schematic representation of the antenna system of Fig. 3.

Figs. 5A-5D show modified receiver-side configurations of the antenna system of the present invention.

DETAILED DESCRIPTION OF THE DRAWINGS

The apparatus of the present invention, represented in Figs. 3 and 4, comprises an antenna 15, which may be electronically tuned, needs low transmitter power, is small in size and is multi-orientable, has high sensitivity at reception and is inherently fail-safe. The magnets (shown in Figs. 1 and 2) for producing a static magnetic field are not shown in Fig. 3 for ease of illustration.

The antenna 15 comprises at least two electromagnetically coupled resonant circuits 27, 28. The inductance coil 16, 17 in each resonant circuit 27, 28 produces an RF field enclosing the examination object (not shown, but see Fig. 1) sometimes somewhat inadequately. The electromagnetic interaction 24 between the resonant circuits 27, 28 results in a combined RF field, which excites the nuclei of the full volume of interest and also intercepts the signal emitted by those nuclei as they relax from their higher energy state.

The first resonance circuit 27 has a first variable capacitance 23, the variation in capacitance of which causes a shift in the resonant frequency of the first resonant circuit 27, and also of the resonance frequency of the combined resonant circuits 27, 28. The first capacitance 23 is connected in parallel to the first inductance coil 16. The resonant circuit 27 comprising the first inductance coil 16 and first capacitance 23 is connected through a switch 18 to a source of RF transmitting power 20. The switch 18 is shown schematically as a mechanical switch in Figs. 3 and 4 for ease of description, but is preferably implemented as an electronic switch, as described later. The switch 18 is in a closed position when the transmitter RF power is delivered to the antenna 15, allowing the power to excite the nuclei in the examination object. At other times the switch 18 is open, as shown in Figs. 3 and 4.

The second resonant circuit 28 is comprised of the second inductance coil 17 connected in series with a varactor 22 which serves as a variable capacitance, an

auxiliary inductance 26 and a fixed second capacitance 25. The second capacitance 25 may be made variable, as desired. Varying the varactor capacitance 22 causes a shift in the resonant frequency of the combined resonant circuit (comprising resonant circuits 27 and 28). A receiver 21 picks up the signal emitted by the examination body (object, patient) by being connected to the second resonant circuit 28 in parallel with the varactor 22. A switch 19 is coupled to short out the inductance coil 26, varactor 22 and receiver 21, and is operated synchronously with the switch 18. That is, both switches 18 and 19 are closed when transmitting RF power is delivered; and both switches 18 and 19 are open at other times (as shown in Fig. 3). The switch 19 is shown schematically in Figs. 3 and 4 as a mechanical switch for ease of description, but is preferably implemented as an electronic switch, as described later.

When the switch 19 is closed, the second resonant circuit 28 is transformed to effectively be comprised of two elements: the second inductance coil 17 and the second capacitance 25, and the resonant frequency of the transformed second resonant circuit 28 is such that the combined resonant frequency of the antenna 15 matches the frequency of the RF transmitting source 20, which is the examination object's Larmor frequency. The necessary tuning is provided by means of varying the first variable capacitance 23 or, if desired, by varying the capacitance of the second capacitance 25. The RF power from transmitter 20 is thus properly delivered into the examination object. At the same time, during RF power transmission, the shorting switch 19 (which is closed) prevents the power from reaching the varactor 22 and receiver 21, hence protecting them from destruction due to high power levels at transmission.

At reception, when both of the switches 18, 19 are open, the RF power source (transmitter) 20 is disconnected from the antenna 15, the varactor capacitance 22 is a part of the second resonant circuit 28 and is set to define the resonant frequency of the combined resonant circuits 27, 28 to match

the Larmor frequency of the relaxing nuclei. The signal from the second resonant circuit 28 is fed to the RF signal receiver 21. The inductance of the auxiliary inductance coil 26 is chosen in such a way as to maintain the resonant frequency range through switching transformations of the second resonant circuit 28. The second resonance circuit 28 can also be used in a detuned mode during transmission, if the spacial positioning of the second inductance coil 17 and its interaction with the first resonant circuit 27 is such that the RF transmitting field flux maintains its proper shape and coverage. As explained later (see Figs. 5A-D), omission of the auxiliary inductance 26 alone or together with the capacitance 25 is then possible, as well as different modifications of the second resonant circuit 28.

The first and second inductance coils 16, 17 comprising the antenna 15 are positioned in close proximity to each other and, as such, they normally have a level of electromagnetic coupling between them of about a few percent. This low level of interaction leads to a frequency response curve of the combined resonant circuits 27, 28 which approximates a multiplication of the frequency response curves of each member circuit 27, 28. The result is higher selectivity and sensitivity of the antenna 15 as compared to an antenna having only a single resonant circuit. Varactor 22 provides accurate and speedy tuning of the antenna 15 at reception, which is essential for optimal extraction of the signal from background noise at varying load conditions.

At transmission, the antenna 15 can be made substantially indifferent to load variations by using an ohmic resistance R (preferably less than 1 ohm) (see Fig. 3A) on the transmitter side of the first switch 18, which effectively widens the combined resonant circuits' bandwidth. The not-shown parts of the system of Fig. 3A are the same as shown in Fig. 3. This approach of Fig. 3A, which widens the bandwidth, avoids the necessity of antenna tuning with replacement of examination objects (patients), at the expense

of slightly higher transmitter RF power. The increase in RF power is negligible for most applications, as the initial RF power requirements are low because of the proximity of the antenna 15 to the examination object. At reception, the antenna 15 retains its high selectivity properties. The series resistor R of Fig. 3A could be placed in parallel with the output of RF transmitter 20, to achieve similar results. In this case, the resistance of the parallel resistor must be large.

The antenna 15 can be positioned at a multitude of orientations in an MRI or NMR apparatus as long as its electrical axis remains perpendicular to the static magnetic field orientation. It is, therefore, particularly suitable for kinematic orthopaedic examinations.

The antenna 15 of the present invention is fail-safe: unintended or excessive RF power delivery is avoided by automatic detuning of the antenna in the case of antenna component failure. Since the two resonant circuits 27, 28 interact to produce a combined tuning effect, if one component fails, the whole system is detuned, and the delivered power drops, thus preventing damage to the object or patient under examination. The system also has low initial power requirements because the antennas are configured for the desired use, and lower power is thus used in many cases, thereby making the antenna system even more fail-safe.

Fig. 3B shows a simple implementation of the switches 18 as respective pairs of oppositely interconnected diodes, and Fig. 3C shows a simple implementation of the switch 19 as a pair of oppositely interconnected diodes. Such diode switches are shown, for example, in U. S. Patent No. 4,975,644 (Fig. 8). Other electronic switching arrangements could be used; see for example U. S. Patent No. 5,144,244. In operation, the diode switching arrangement of Figs. 3B and 3C is automatic. That is, when the transmitter is turned on to transmit an RF signal, the high power output of the transmitter, during the positive half cycle of the AC RF

signal, causes the diode connected in the forward direction to conduct, and the diode connected in the reverse direction does not conduct. During the negative half cycle of the AC RF signal, the diode connected in the reverse direction conducts and the diode connected in the forward direction does not conduct. Each pair of diodes operates in a similar manner. When the transmitter 20 is turned off, the stray signals in the system are not sufficient to cause the diodes to conduct, even in their respective forward directions, thereby effectively isolating the transmitter 20 from the resonant circuits during times when the transmitter 20 is turned off. Similarly, at the receiver side, when the transmitter 20 is turned on, the RF signals passing through the diodes in Fig. 3C are sufficiently large to cause the diodes to conduct in their respective forward directions (during the positive and negative half cycles, respectively) to effectively short out the input of the receiver 21. When the transmitter 20 is turned off, the signals flowing through the circuit are sufficiently low that the diodes 19 are not turned on, even in their forward directions, thereby appearing as an open circuit and permitting the received signals to be forwarded to the RF signal receiver 21.

If higher threshold switching voltages are required, two or more series connected diodes can be used in place of each diode shown in Figs. 3B and 3C, for example as shown in Fig. 8 of U. S. Patent No. 4,975,644.

Those skilled in the art will recognize that the potential implementations of the antenna of the present invention are numerous and application driven. The Larmor frequency, the nature of the examination object and magnetic field orientation will prescribe the specified antenna's shape, size and components. It will also be clear that a multitude of components can be used instead of those specifically described. For example, as mentioned above, a pair of parallel and oppositely interconnected diodes (or other electronic switching arrangements) can be used in place of each switching pole 18, 19, a set of capacitors including

stray capacitance can be used in place of any single capacitor, and any type and number of variable capacitors can be used in place of varactor 22. Also, standard consideration should be given to stray reactances and to impedance matching of the transmitter 20 and receiver 21.

The impedance matching circuitry is presumed to be integral parts of the RF signal transmitter 20, and RF signal receiver 21, respectively.

The system could be configured so that (I) during transmission the resonant circuit 28 is tuned to the transmitter frequency, or (II) during transmission the resonant circuit 28 is detuned with respect to the transmitter frequency. The conditions I and II are shown in Figs. 5A-5D. In each case, switch 19 is closed during transmission. In Figs. 5A and 5D, the conditions I and II are determined by the values of the components of the circuit. In Fig. 5A, the switches 19', which are connected in series with inductance 26', close (during the respective positive and negative half cycles) during transmission due to the high transmission power level. Only receiver-side circuits are shown in Figs. 5A-5D. The transmission side is as shown in Figs. 3 and/or 4 (and/or as modified by Figs. 3A or 3B).

It will be appreciated that the instant specification is set forth by way of illustration and not limitation, and that various modifications and changes may be made without departing from the spirit and scope of the present invention.

CLAIMS:

1. An antenna system for use in a nuclear magnetic resonance or magnetic resonance imaging apparatus which includes a radio frequency (RF) signal transmitter and a radio frequency (RF) signal receiver, the antenna system comprising:

at least first and second electromagnetically coupled resonant circuits;

said first resonant circuit comprising a first inductance coil producing a first electromagnetic field flux vector;

said second resonant circuit comprising a second inductance coil producing a second electromagnetic field flux vector;

said first and second inductance coils being electromagnetically coupled such that the first electromagnetic field flux vector has a component parallel to the second electromagnetic field flux vector; and

a switch system coupled to said first resonant circuit and to said second resonant circuit, said switch system having:

a first switching position for coupling said first resonant circuit to an output of said RF signal transmitter and for preventing a signal from said second resonant circuit from being fed to an input of said RF signal receiver, and

a second switching position for permitting an RF signal from said second resonant circuit to be fed to an input of said RF signal receiver and for disconnecting said first resonant circuit from the output of said RF signal transmitter;

and wherein:

at least said first inductance coil produces an electromagnetic field flux enclosing an examination object therewithin, which electromagnetic field flux is used to

irradiate the examination object, when said switch system is in the first switching position; and

an electromagnetic field flux produced by a signal emitted by the examination object's relaxing nuclei is picked up by said electromagnetically coupled inductance coils and is fed to said RF signal receiver via said second resonant circuit, when said switch system is in the second switching position.

2. The antenna system of claim 1, wherein:

said first resonant circuit comprises at least a first capacitance connected in parallel with said first inductance coil, and comprising together with said first inductance coil the first resonant circuit, and wherein at least said first capacitance is used for frequency tuning of the antenna system at least during transmission; and

said switch system includes at least one first switching element connecting said first resonant circuit to said RF signal transmitter output in said first switching position and disconnecting said first resonant circuit from said RF signal transmitter output in said second switching position.

3. The antenna system of claim 2, wherein said first capacitance comprises a variable capacitor element.

4. The antenna system of claim 2, wherein:

said second resonant circuit comprises:

a variable capacitance element, coupled for frequency tuning of the antenna circuitry and for feeding an RF signal to an input of said RF receiver;

a second capacitance; and

an auxiliary inductance for roughly matching an impedance of said second capacitance;

said second capacitance, said variable capacitance element and said auxiliary inductance being coupled together and being further coupled to said second inductance coil; and

said switch system includes a second switching element coupled to selectively short out at least said variable capacitance element and said RF receiver input, and for electrically removing at least said variable capacitance element, and said RF receiver input from said second resonance circuit, in said first switching position, and said second switching element being electrically open and having no electrical effect in said second switching position.

5. The antenna circuitry of claim 4, wherein said variable capacitance element comprises at least one varactor.

6. The antenna system of claim 4, wherein said first capacitance comprises a variable capacitor element.

7. The antenna system of claim 1, wherein:

said second resonant circuit comprises:

a variable capacitance element, coupled for frequency tuning of the antenna circuitry and for feeding an RF signal to an input of said RF receiver;

a second capacitance; and

an auxiliary inductance for roughly matching an impedance of said second capacitance;

said second capacitance, said variable capacitance element and said auxiliary inductance being coupled together and being further coupled to said second inductance coil; and

said switch system includes a second switching element coupled to selectively short out at least said variable capacitance element and said RF receiver input, and for electrically removing at least said variable capacitance element, and said RF receiver input from said second resonance circuit, in said first switching position, and said second switching element being electrically open and having no electrical effect in said second switching position.

8. The antenna circuitry of claim 7, wherein said variable capacitance element comprises at least one varactor.

9. The antenna system of claim 7, wherein said first resonant circuit comprises a capacitor element connected to said first inductance coil.

10. The antenna system of claim 7, wherein said second capacitance, said variable capacitance element and said auxiliary inductance are connected in a series connection.

11. The antenna system of claim 10, wherein said series connection is serially connected with said second inductance coil.

12. The antenna system of claim 7, wherein said auxiliary inductance is connected in series with a switch device, the series connection being connected in parallel with said second capacitance.

13. The antenna system of claim 1, wherein said switch system comprises:

at least a first pair of opposite polarity, parallel connected, diodes coupled to an output of said RF signal transmitter; and

at least a second pair of opposite polarity, parallel connected, diodes coupled across the input of said RF signal receiver.

14. The antenna system of claim 1, further comprising a resistance coupled to an output of said RF signal transmitter.

15. The antenna system of claim 1, wherein:

said second resonant circuit comprises:

a variable capacitance element, coupled for frequency tuning of the antenna circuitry and for feeding an RF signal to an input of said RF receiver;

a second capacitance; and

said second capacitance and said variable capacitance element being connected to said second inductance coil; and

said switch system includes a second switching element coupled to selectively short out said variable capacitance element and said RF receiver input, and for electrically removing at least said variable capacitance element, and said RF receiver input from said second resonance circuit, in said first switching position, and said second switching element being electrically open and having no electrical effect in said second switching position.

16. The antenna circuitry of claim 15, wherein said variable capacitance element comprises a varactor.

17. The antenna system of claim 15, wherein said first resonant circuit comprises a capacitor element connected to said first inductance coil.

18. The antenna system of claim 1, wherein:

said second resonant circuit comprises:

a variable capacitance element, coupled for frequency tuning of the antenna circuitry and for feeding an RF signal to an input of said RF receiver;

said variable capacitance element being coupled to said second inductance coil; and

said switch system includes a second switching element coupled to selectively short out said variable capacitance element and said RF receiver input, and for electrically removing said variable capacitance element and said RF receiver input from said second resonance circuit, in said first switching position, and said second switching element being electrically open and having no electrical effect in said second switching position.

19. The antenna circuitry of claim 18, wherein said variable capacitance element comprises a varactor.

20. The antenna system of claim 18, wherein said first resonant circuit comprises a capacitor element connected to said first inductance coil.

21. A method of operating an antenna system in a nuclear magnetic resonance or magnetic resonance imaging apparatus which includes a radio frequency (RF) signal transmitter and a radio frequency (RF) signal receiver, the method comprising:

providing at least first and second electromagnetically coupled resonant circuits;

said first resonant circuit comprising a first inductance coil producing a first electromagnetic field flux vector;

said second resonant circuit comprising a second inductance coil producing a second electromagnetic field flux vector;

causing said first and second inductance coils to be electromagnetically coupled such that the first electromagnetic field flux vector has a component parallel to the second electromagnetic field flux vector; and

switching said first resonant circuit and said second resonant circuit with a switch system such that:

when said switch system is in a first switching position, said first resonant circuit is coupled to an output of said RF signal transmitter, and a signal from said second resonant circuit is prevented from being fed to an input of said RF signal receiver, and

when said switch system is in a second switching position, an RF signal from said second resonant circuit is fed to an input of said RF signal receiver and said first resonant circuit is disconnected from the output of said RF signal transmitter;

and wherein:

at least said first inductance coil produces an electromagnetic field flux enclosing an examination object therewithin, which electromagnetic field flux is used to

irradiate the examination object, when said switch system is in the first switching position; and

an electromagnetic field flux produced by a signal emitted by the examination object's relaxing nuclei is picked up by said electromagnetically coupled inductance coils and is fed to said RF signal receiver via said second resonant circuit, when said switch system is in the second switching position.

22. The method of claim 21, wherein:

the frequency response of said first and second resonant circuits is set independently and separately in the first and second switching positions.

23. The method of claim 21, wherein the antenna system is positioned at any angle orthogonal to a static magnetic field of the apparatus.

24. The method of claim 21, comprising maintaining said first and second resonant circuits tuned to the object's Larmor frequency when said switch system is in said first switching position.

25. The method of claim 21, comprising detuning said second resonant circuit from the object's Larmor frequency when said switch system is in said first switching position.

26. The method of claim 21, wherein said first and second resonant circuits are tuned to the object's Larmor frequency when said switch system is in said second switching position.

AMENDED CLAIMS

[received by the International Bureau on 21 November 1997 (21.11.97); original claims 1, 2, 4, 7, 9, 13, 15, 17, 18, 20-22 and 24-26 amended; new claims 27-35 added; remaining claims unchanged (10 pages)]

1. An antenna system for use in a nuclear magnetic resonance or magnetic resonance imaging apparatus which includes a radio frequency (RF) signal transmitter and a radio frequency (RF) signal receiver, the antenna system comprising:

at least first and second electromagnetically coupled circuits;

said first circuit comprising a first inductance coil producing a first electromagnetic field flux vector;

said second circuit comprising a second inductance coil producing a second electromagnetic field flux vector;

said first and second inductance coils being electromagnetically coupled such that the first electromagnetic field flux vector has a component interacting with a component of the second electromagnetic field flux vector; and

a switch system coupled to said first circuit and to said second circuit, said switch system having:

a first switching position for coupling said first circuit to an output of said RF signal transmitter and for preventing a damaging level of signal from said second circuit from being fed to an input of said RF signal receiver, and

a second switching position for permitting an RF signal from said second circuit to be fed to an input of said RF signal receiver and for decoupling said first circuit from the output of said RF signal transmitter; and wherein:

said antenna system produces an electromagnetic field flux enclosing an examination object therewithin, which electromagnetic field flux is used to

irradiate the examination object, when said switch system is in the first switching position; and

an electromagnetic field flux produced by a signal emitted by the examination object's relaxing nuclei is picked up by said electromagnetically coupled inductance coils and is fed to said RF signal receiver via said second circuit, when said switch system is in the second switching position.

2. The antenna system of claim 1, wherein:

said first circuit comprises at least a first capacitance connected in parallel with said first inductance coil, and comprising together with said first inductance coil the first circuit, and wherein at least said first capacitance is used for frequency tuning of the antenna system at least during transmission; and

said switch system includes at least one first switching element coupling said first circuit to said RF signal transmitter output in said first switching position and decoupling said first circuit from said RF signal transmitter output in said second switching position.

3. The antenna system of claim 2, wherein said first capacitance comprises a variable capacitor element.

4. The antenna system of claim 2, wherein:

said second circuit comprises:

a variable capacitance element, coupled for frequency tuning of the antenna circuitry;

a second capacitance; and

an auxiliary inductance for roughly matching an impedance of said second capacitance;

said second capacitance, said variable capacitance element and said auxiliary inductance being coupled together and being further coupled to said second inductance coil; and

said switch system includes a second switching element coupled to selectively short out at least said variable capacitance element and said RF receiver input, and for electrically removing at least said variable capacitance element and said RF receiver input from said second circuit, in said first switching position, and said second switching element being electrically open and having substantially no electrical effect in said second switching position.

5. The antenna circuitry of claim 4, wherein said variable capacitance element comprises at least one varactor.

6. The antenna system of claim 4, wherein said first capacitance comprises a variable capacitor element.

7. The antenna system of claim 1, wherein:

said second circuit comprises:

a variable capacitance element, coupled for frequency tuning of the antenna circuitry;

a second capacitance; and

an auxiliary inductance for roughly matching an impedance of said second capacitance;

said second capacitance, said variable capacitance element and said auxiliary inductance being coupled together and being further coupled to said second inductance coil; and

said switch system includes a second switching element coupled to selectively short out at least said variable capacitance element and said RF receiver input, and for electrically removing at least said variable capacitance element and said RF receiver input from said second circuit, in said first switching position, and said second switching element being electrically open and having substantially no electrical effect in said second switching position.

8. The antenna circuitry of claim 7, wherein said variable capacitance element comprises at least one varactor.

9. The antenna system of claim 7, wherein said first circuit comprises a capacitor element connected to said first inductance coil.

10. The antenna system of claim 7, wherein said second capacitance, said variable capacitance element and said auxiliary inductance are connected in a series connection.

11. The antenna system of claim 10, wherein said series connection is serially connected with said second inductance coil.

12. The antenna system of claim 7, wherein said auxiliary inductance is connected in series with a switch device, the series connection being connected in parallel with said second capacitance.

13. The antenna system of claim 1, wherein said switch system comprises:

at least a first pair of opposite polarity, parallel connected, diodes coupled to an output of said RF signal transmitter; and

at least a second pair of opposite polarity, parallel connected, diodes coupled across an input of said RF signal receiver.

14. The antenna system of claim 1, further comprising a resistance coupled to an output of said RF signal transmitter.

15. The antenna system of claim 1, wherein:

said second circuit comprises:

a variable capacitance element, coupled for frequency tuning of the antenna circuitry;

a second capacitance; and

said second capacitance and said variable capacitance element being connected to said second inductance coil; and

said switch system includes a second switching element coupled to selectively short out at least said variable capacitance element and said RF receiver input, and for electrically removing at least said variable capacitance element and said RF receiver input from said second circuit, in said first switching position, and said second switching element being electrically open and having substantially no electrical effect in said second switching position.

16. The antenna circuitry of claim 15, wherein said variable capacitance element comprises a varactor.

17. The antenna system of claim 15, wherein said first circuit comprises a capacitor element connected to said first inductance coil.

18. The antenna system of claim 1, wherein:

said second circuit comprises:

a variable capacitance element, coupled for frequency tuning of the antenna circuitry;

said variable capacitance element being coupled to said second inductance coil; and

said switch system includes a second switching element coupled to selectively short out at least said variable capacitance element and said RF receiver input, and for electrically removing said variable capacitance element and said RF receiver input from said second circuit, in said first switching position, and said second switching element being electrically open and having substantially no electrical effect in said second switching position.

19. The antenna circuitry of claim 18, wherein said variable capacitance element comprises a varactor.

20. The antenna system of claim 18, wherein said first circuit comprises a capacitor element connected to said first inductance coil.

21. A method of operating an antenna system in a nuclear magnetic resonance or magnetic resonance imaging apparatus which includes a radio frequency (RF) signal transmitter and a radio frequency (RF) signal receiver, the method comprising:

providing at least first and second electromagnetically coupled circuits;

said first circuit comprising a first inductance coil producing a first electromagnetic field flux vector;

said second circuit comprising a second inductance coil producing a second electromagnetic field flux vector;

causing said first and second inductance coils to be electromagnetically coupled such that the first electromagnetic field flux vector has a component interacting with a component of the second electromagnetic field flux vector; and

switching said first circuit and said second circuit with a switch system such that:

when said switch system is in a first switching position, said first circuit is coupled to an output of said RF signal transmitter, and a damaging level of signal from said second circuit is prevented from being fed to an input of said RF signal receiver, and

when said switch system is in a second switching position, an RF signal from said second circuit is fed to an input of said RF signal receiver and said first circuit is decoupled from an output of said RF signal transmitter;

and wherein:

said antenna system produces an electromagnetic field flux enclosing an examination object therewithin, which electromagnetic field flux is used to

irradiate the examination object, when said switch system is in the first switching position; and

an electromagnetic field flux produced by a signal emitted by the examination object's relaxing nuclei is picked up by said electromagnetically coupled inductance coils and is fed to said RF signal receiver via said second circuit, when said switch system is in the second switching position.

22. The method of claim 21, wherein:

the frequency response and the electromagnetic field flux of said antenna system is set independently and separately in the first and second switching positions.

23. The method of claim 21, wherein the antenna system is positioned at any angle orthogonal to a static magnetic field of the apparatus.

24. The method of claim 21, comprising maintaining said antenna system tuned to the object's Larmor frequency when said switch system is in said first switching position.

25. The method of claim 21, comprising detuning said second circuit from the object's Larmor frequency when said switch system is in said first switching position.

26. The method of claim 21, wherein said antenna system is tuned to the object's Larmor frequency when said switch system is in said second switching position.

27. An antenna system for use in a nuclear magnetic resonance or magnetic resonance imaging apparatus which includes a radio frequency (RF) signal transmitter and a radio frequency (RF) signal receiver, the antenna system comprising:

at least one circuit, including an inductance coil, for producing an electromagnetic field flux vector; and

a switch system coupled to said at least one circuit, said switch system having:

a first switching position for coupling said at least one circuit to an output of said RF signal transmitter and for preventing a damaging level of signal from said at least one circuit from being fed to an input of said RF signal receiver, and

a second switching position for permitting an RF signal from said at least one circuit to be fed to an input of said RF signal receiver and for decoupling said at least one circuit from the output of said RF signal transmitter;

and wherein:

said antenna system produces an electromagnetic field flux enclosing an examination object therewithin, which electromagnetic field flux is used to irradiate the examination object, when said switch system is in the first switching position; and

an electromagnetic field flux produced by a signal emitted by the examination object's relaxing nuclei is picked up by said at least one circuit and is fed to said RF signal receiver, when said switch system is in the second switching position.

28. The antenna system of claim 27, wherein:

said at least one circuit comprises at least a first capacitance connected in parallel with said inductance coil, and wherein at least said first capacitance is used for frequency tuning of the antenna system at least during transmission; and

said switch system includes at least one first switching element coupling said at least one circuit to said RF signal transmitter output in said first switching position and decoupling said at least one circuit from said RF signal transmitter output in said second switching position.

29. The antenna system of claim 28, wherein said first capacitance comprises a variable capacitor element.

30. The antenna system of claim 28, wherein:

said at least one circuit further comprises a second capacitance, said second capacitance comprising a variable capacitance element coupled to said inductance coil for frequency tuning at least during reception when said switch system is in the second switching position; and

said switch system includes a second switching element coupled to selectively effectively short out at least said variable capacitance element and said RF receiver input, and for thereby electrically removing at least said variable capacitance element and said RF receiver input from said at least one circuit when said switch system is in the first switching position, and said second switching element being electrically open and having substantially no electrical effect when said switch system is in said second switching position.

31. A method of operating an antenna system in a nuclear magnetic resonance or magnetic resonance imaging apparatus which includes a radio frequency (RF) signal transmitter and a radio frequency (RF) signal receiver, the method comprising:

providing at least one circuit including an inductance coil, for producing an electromagnetic field flux vector; and

switching said at least one circuit with a switch system such that:

when said switch system is in a first switching position, said at least one circuit is coupled to an

AMENDED SHEET (ARTICLE 19)

output of said RF signal transmitter, and a damaging level of signal from said at least one circuit is prevented from being fed to an input of said RF signal receiver, and

when said switch system is in a second switching position, an RF signal from said at least one circuit is fed to an input of said RF signal receiver and said at least one circuit is decoupled from an output of said RF signal transmitter;

and wherein:

said antenna system produces an electromagnetic field flux enclosing an examination object therewithin, which electromagnetic field flux is used to irradiate the examination object, when said switch system is in the first switching position; and

an electromagnetic field flux produced by a signal emitted by the examination object's relaxing nuclei is picked up by said at least one circuit and is fed to said RF signal receiver when said switch system is in the second switching position.

32. The method of claim 31, comprising frequency tuning the antenna system with a capacitance coupled to said inductance coil.

33. The method of claim 32, wherein said capacitance comprises a variable capacitance for frequency tuning the antenna system.

34. The method of claim 32, comprising maintaining said antenna system tuned to the object's Larmor frequency when said switch system is in said first switching position.

35. The method of claim 32, wherein said antenna system is tuned to the object's Larmor frequency when said switch system is in said second switching position.

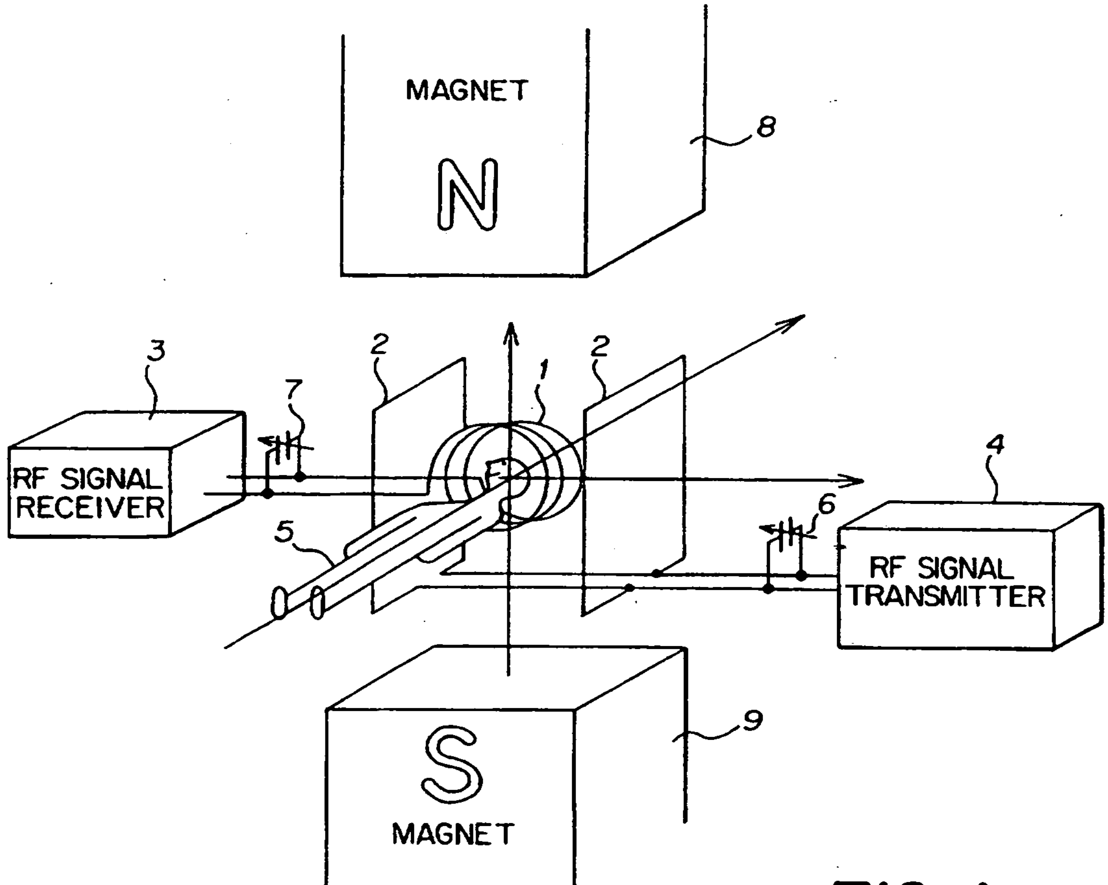

FIG. 1
(PRIOR ART)

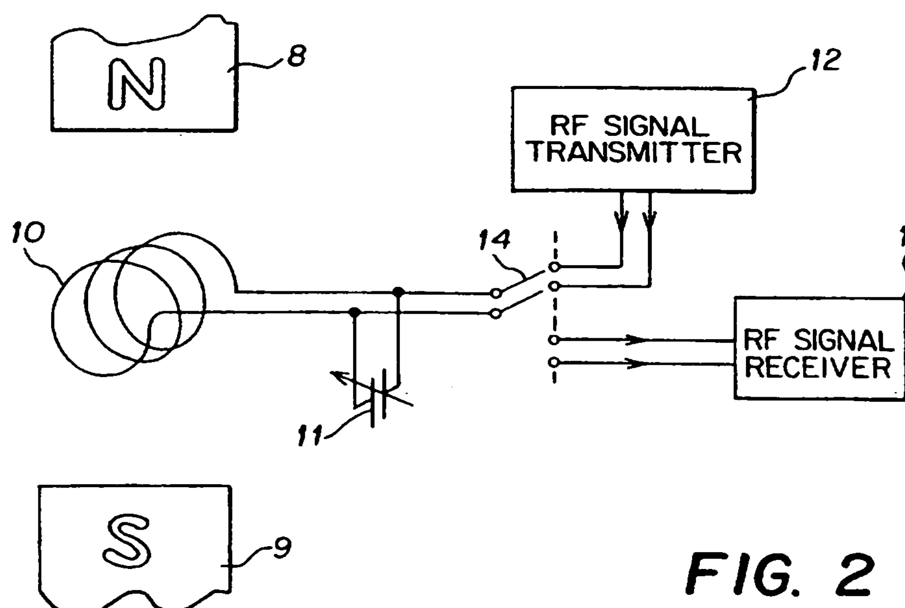

FIG. 2
(PRIOR ART)

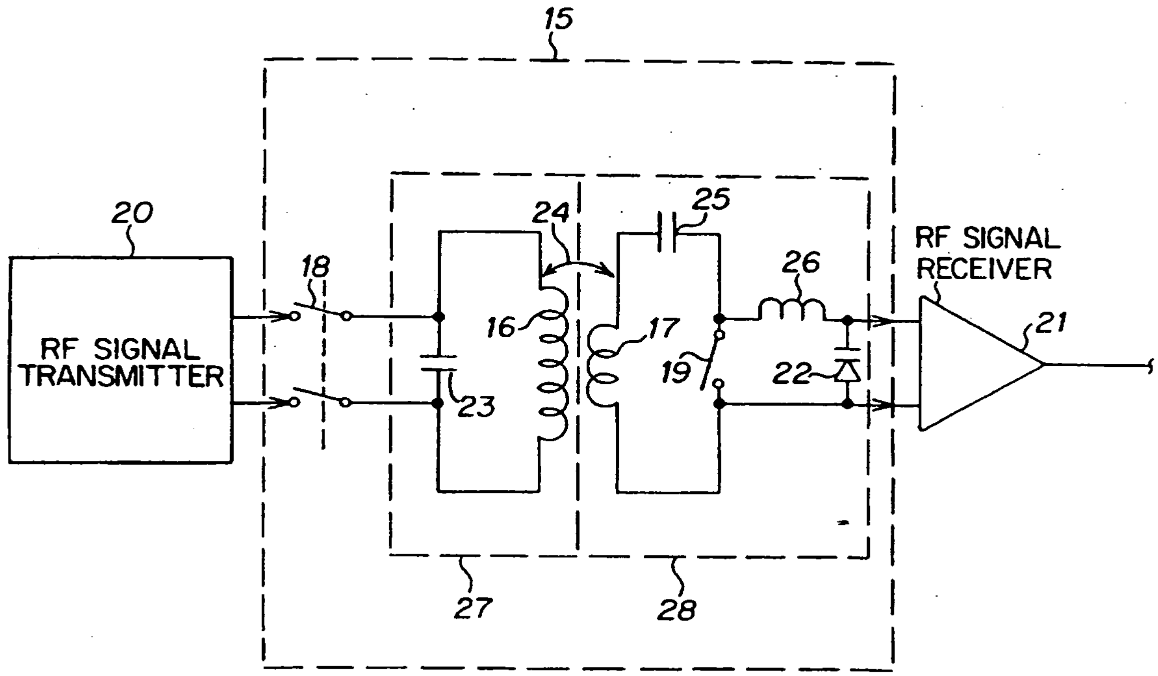

FIG. 3

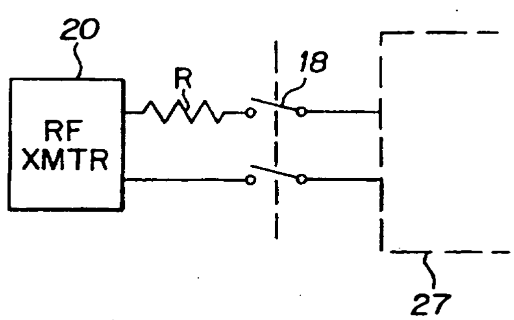

FIG. 3A

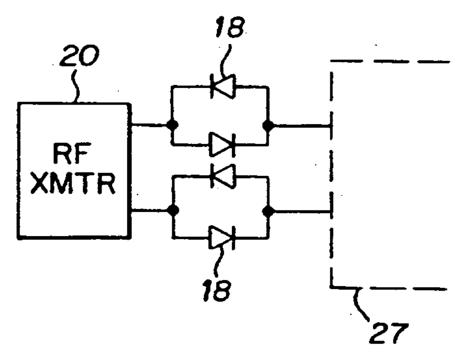

FIG. 3B

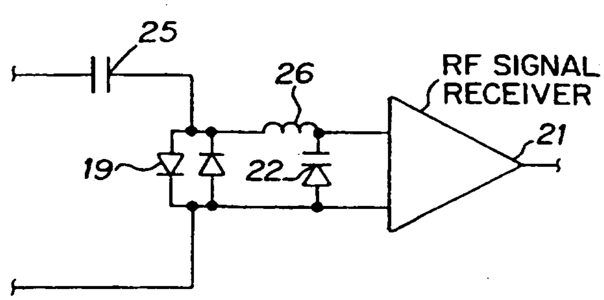

FIG. 3C

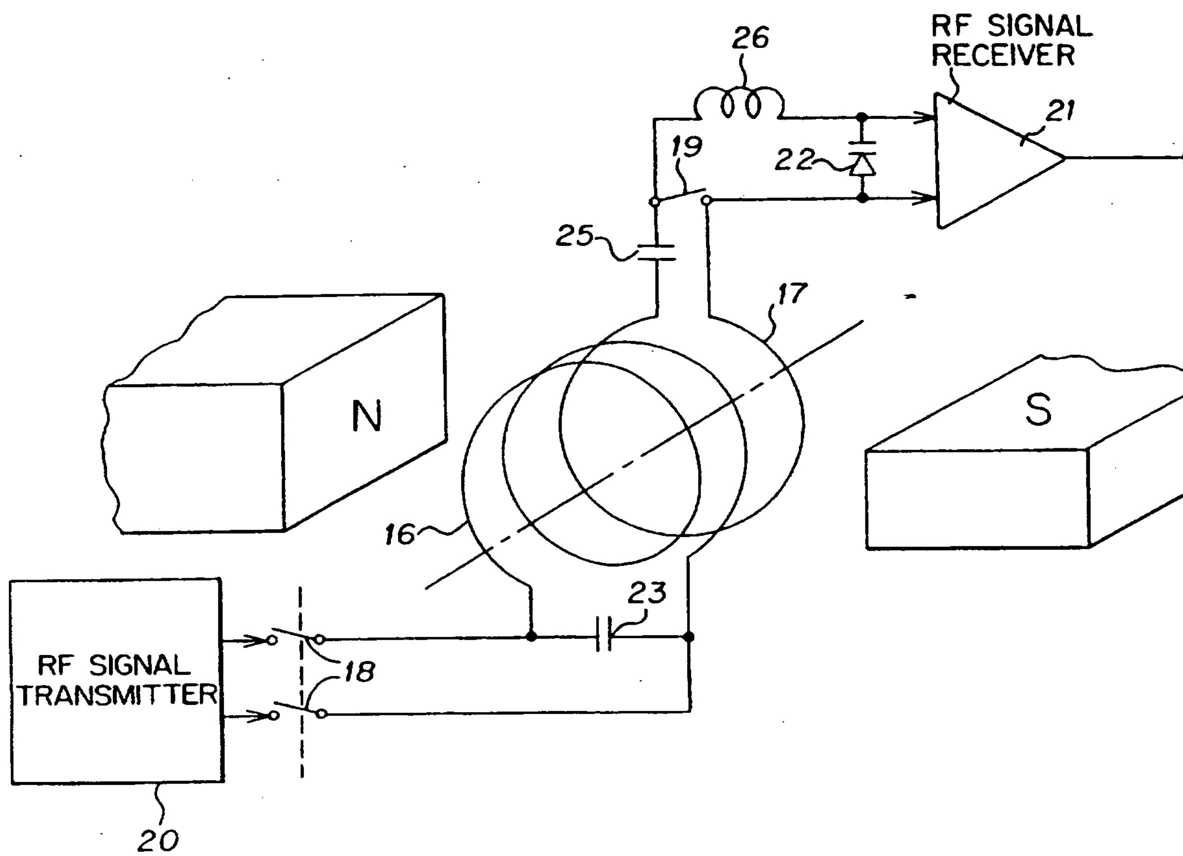
26
RF SIGNAL
RECEIVER
21
19
22
25
17
N
S
16
23
RF SIGNAL
TRANSMITTER
18
20

FIG. 4

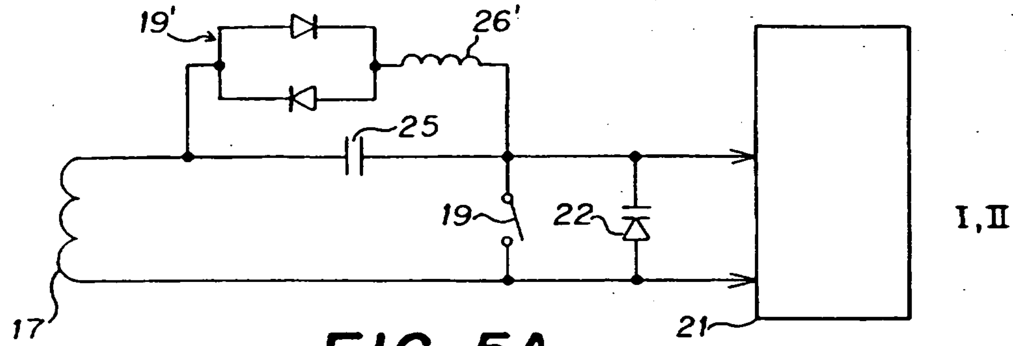

FIG. 5A

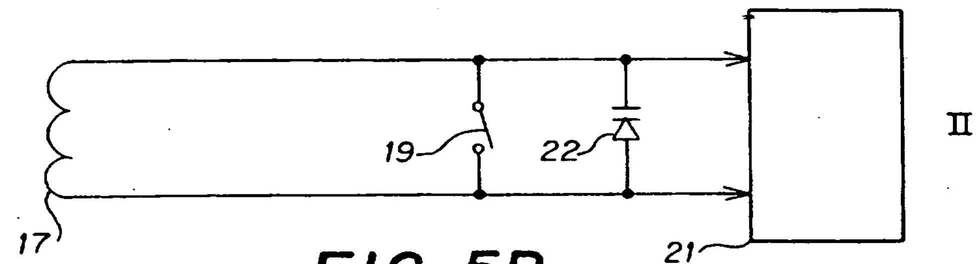

FIG. 5B

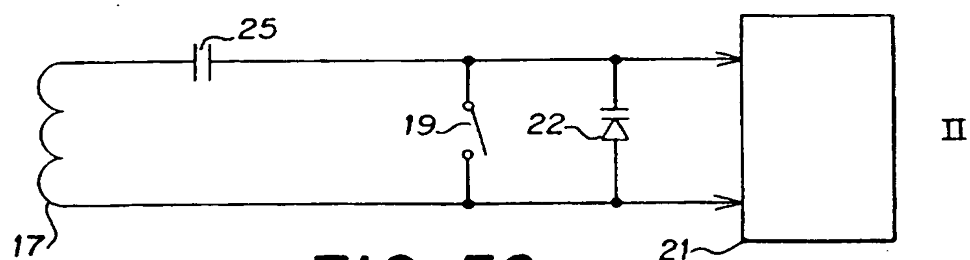

FIG. 5C

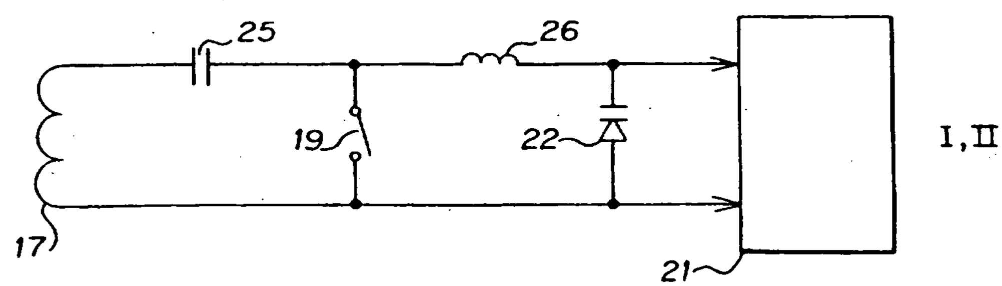

FIG. 5D

INTERNATIONAL SEARCH REPORT

International application No.
PCT/US97/09420

A. CLASSIFICATION OF SUBJECT MATTER

IPC(6) :G01V 3/00
US CL :324/318
According to International Patent Classification (IPC) or to both national classification and IPC

B. FIELDS SEARCHED

Minimum documentation searched (classification system followed by classification symbols)

U.S. : 324/318, 322, 314, 300, 307, 319

Documentation searched other than minimum documentation to the extent that such documents are included in the fields searched

none

Electronic data base consulted during the international search (name of data base and, where practicable, search terms used)

none

C. DOCUMENTS CONSIDERED TO BE RELEVANT

Category*	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
A	US, A, 5,202,634 (POTTHAST ET AL.) 13 APRIL 1993 (13.04.93) See Fig. 2 and the abstract of the disclosure.	1-26
A	US, A, 5,317,266 (MEISSNER) 31 MAY 1994 (31.05.94) See col. 2 and the abstract of the disclosure.	1-26

☐ Further documents are listed in the continuation of Box C. ☐ See patent family annex.

* Special categories of cited documents:

"A" document defining the general state of the art which is not considered to be of particular relevance

"E" earlier document published on or after the international filing date

"L" document which may throw doubts on priority claim(s) or which is cited to establish the publication date of another citation or other special reason (as specified)

"O" document referring to an oral disclosure, use, exhibition or other means

"P" document published prior to the international filing date but later than the priority date claimed

"T" later document published after the international filing date or priority date and not in conflict with the application but cited to understand the principle or theory underlying the invention

"X" document of particular relevance; the claimed invention cannot be considered novel or cannot be considered to involve an inventive step when the document is taken alone

"Y" document of particular relevance; the claimed invention cannot be considered to involve an inventive step when the document is combined with one or more other such documents, such combination being obvious to a person skilled in the art

"&" document member of the same patent family

Date of the actual completion of the international search	Date of mailing of the international search report
17 JULY 1997	14 NOV 1997

Name and mailing address of the ISA/US Commissioner of Patents and Trademarks Box PCT Washington, D.C. 20231 Facsimile No. (703) 305-3230	Authorized officer Diane Goodwyn for LOUIS ARANA Telephone No. (703) 305-4913